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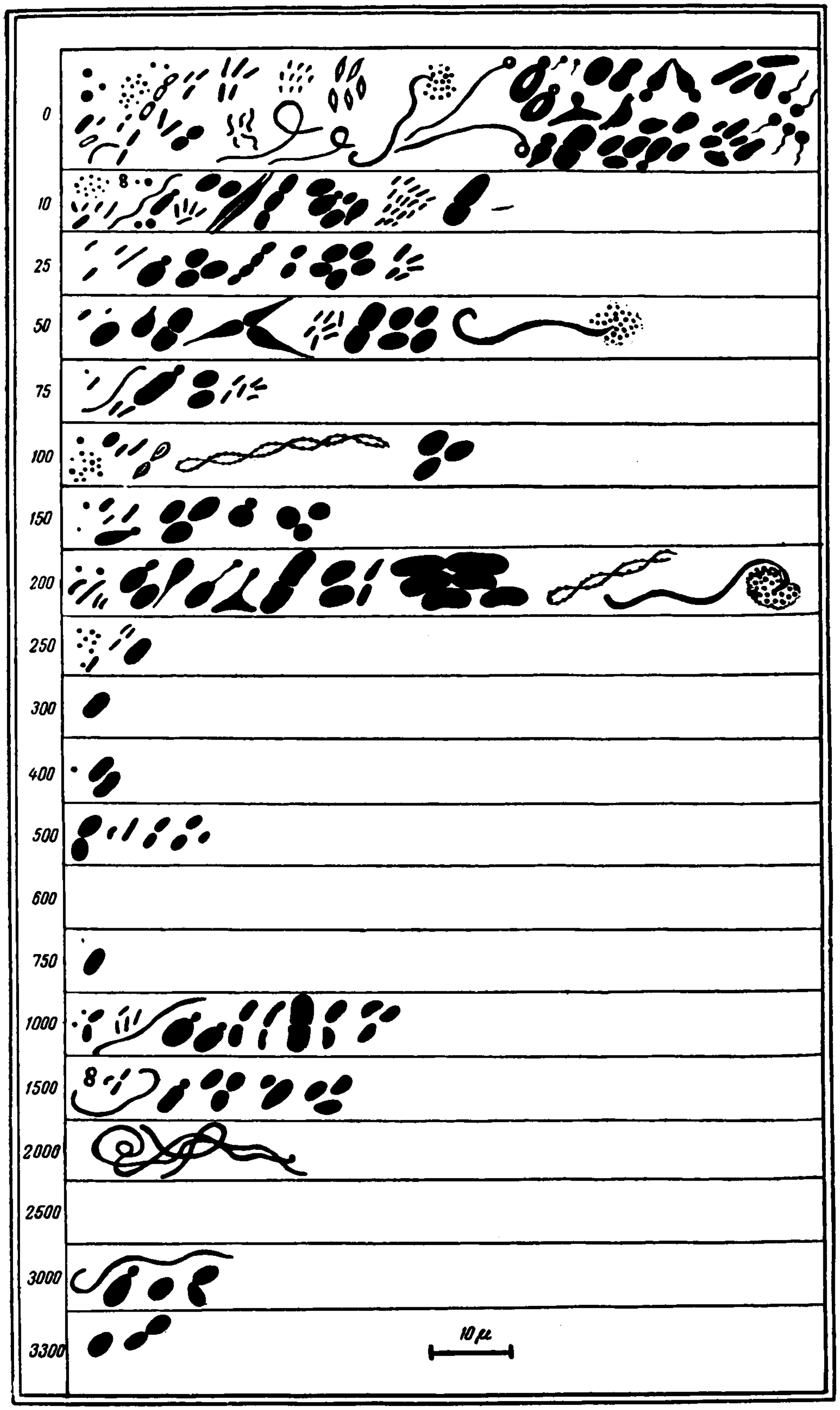

Figure 1. Morphological forms of microorganisms on glass slides after submerging them at different depths of the ocean in the region of the North Pole.

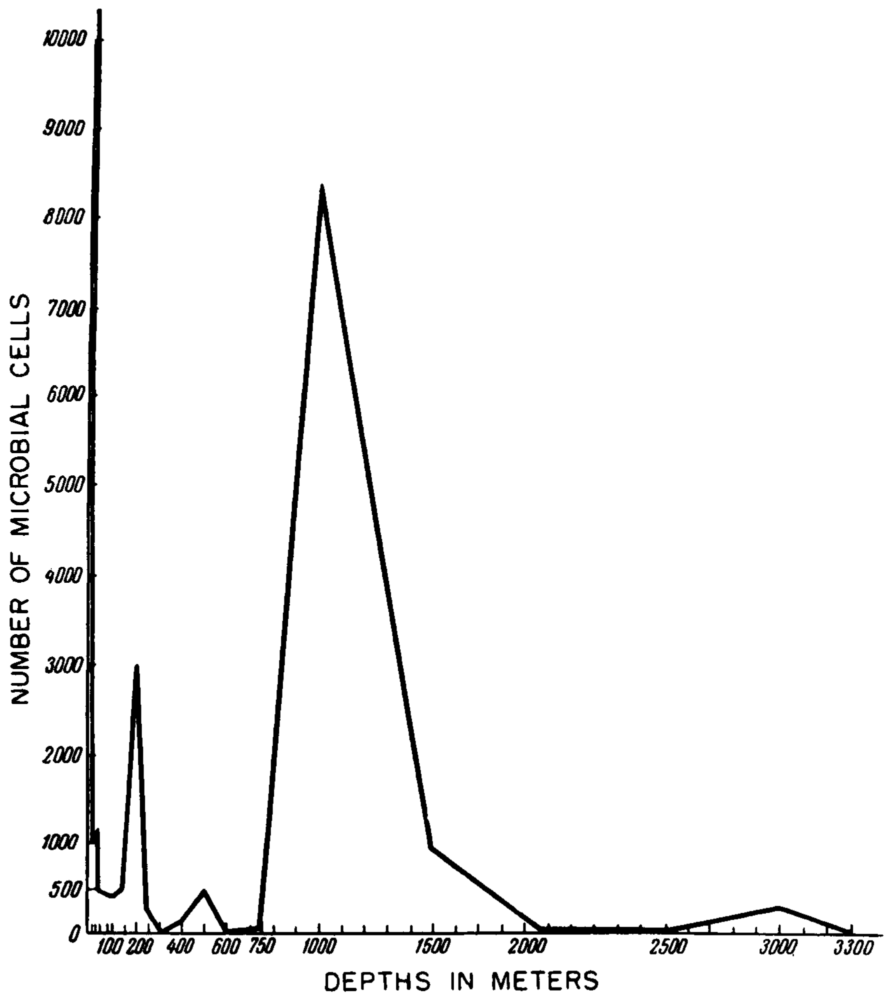

Figure 2. Vertical distribution of the number of microorganisms growing on glass slides in the ocean in the region of the North Pole.

(a

The Rate of Increase in the Number of Microorganisms in the Ocean in the Region of the North Pole.

A. E. Kriss and V. A. Lambina
Uspekhi Sovremennoi Biol., 39: 366-373 (1955)

The organization in the central Arctic of scientific stations on ice opened an opportunity for microbiological study of a fixed type in the high latitude polar basin. Such studies were started in 1954. In July and September, when North Pole-3 in the region of the North Pole started, a microbiological laboratory was organized on it. Investigations were conducted on the normal vertical distribution of microorganisms in all layers of the Arctic Ocean (Kriss, Biruzova, Tikhonenko, & Lambina, 1955; Kriss, 1955).

The program of the microbiological works in the North Pole also included the study of the rate of growth of microorganisms in different depths of the ocean. The method of submerging glass slides to the proper depth of the water mass was applied (Kriss & Rukina, 1952; Kriss & Markianovich, 1954). As is known, in shallow ponds, conditions are created for the adsorption of organic material of the solid and liquid phases for its accumulation and transformation to a form suitable for assimilation by microorganisms. Thanks to this, the latter settle on suspended particles and other objects occurring in ponds, and multiply on them. Glass slides submerged in the ocean show analogous suspended particles of an organic and inorganic nature occurring in all water masses of the ocean from top to bottom.

Soon after glass slides are submerged in ponds, microorganisms settle on them and propagate. Under a microscope can be seen on the glass, side by side with single cells, dividing cells and microcolonies consisting of a few bacteria or even a few hundred microbial cells. If one estimates the number of individuals in each microcolony, and accepts that the latter are produced from a single cell, it is possible, knowing the length of time since submerging the glass, to determine the increase in biomass of microorganisms in a unit of time. This constitutes the principal method for ascertaining the rate of growth of microorganisms in the sea and ocean. With the help of these methods, estimations of the times of multiplication of microbial cells in the Black and Caspian Seas and the Pacific Ocean were derived (Kriss & Markianovich, 1954).

Microbiological observations were made in July 1954 on drifting station "North Pole-3". Coordinates of the station were 88°04'3" north latitude and 151°16' west longitude where the depth of the ocean under the ice was 3450 m. Previously flamed slides, fastened to a cable with the help of rubber chucks, were dropped through a hole in the ice to depths 0, 10, 25, 50, 75, 100, 150, 200, 250, 300, 400, 500, 600, 750, 1000, 1500, 2000, 2500, 3000, 3300 m. At these depths they remained 24 hours after which they were withdrawn, dried, and flamed on one side in a gas flame. These procedures were carried out in the microbiological laboratory on the drifting station.

In Moscow the slides were stained in a stream of essentially 5% carbolic erythrosine, previously filtered through a membrane ultra-filter. The dye was washed off with ultrafiltered water. On the dried slides a rectangle 4 x 2 cm was outlined, going back from the rim and the spot of contact of the slide with the rubber chuck on the cable. All of the area in 8 cm^2 was scanned under the microscope, field after visual field, series after series, and of such on indicated section--100. Microscopy was performed on the side of the glass which was not flamed. With the microscope were counted separately the number of cells from every morphologic group. This afforded the opportunity to ascertain not only the morphological variety of microorganisms deposited on the glass, but also to establish the number of microbic forms differing according to morphology. At the same time computations were made of the number of microcolonies and of the number of cells composing each microcolony.

For convenience of identification the average rate of increase of microorganisms of every microcolony growing on glass was divided in groups depending on the number of cells composing it, singly occurring cells, microcolonies of 3-5, 6-10, 11-25, 26-50, 51-75, and 76-100 cells. Microcolonies consisting of more than 100 cells were recorded as 100.

In figure 1 are represented the forms of microorganisms settled on glass slides in different depths of the Arctic Ocean in the region of the North Pole. The greatest variety was observed in the upper layer--surface to 200 m deep and especially the greatest number of forms--near the surface of the ocean. At depth 250 m the morphological composition of microorganisms settling on the glass became lean, excluding depths 100 and 1500 m, where the variety increased in comparison with upper and lower lying layers of water.

On glass are detected rod-shaped bacteria of diverse dimensions 0.3 x 0.8 to 1 x 5 μ, with blunt, oval, and pointed ends; by a certain precision, a bipolar granule was seen. The forms of the rods--straight or curved, were arranged singly, in pairs, or in colonies. The cocci, from 1 to 2 μ in diameter, had round or slightly oblong forms and generally occurred in the shape of diplococci, short little chains, or little bundles.

There was extensive occurrence of relatively large cells to 5 μ, of spherical, oval, and elongated forms. In many depths, not only at the surface, but also at depths 1000, 1500, and 3000 m, are found budding yeast cells. Thread-like microorganisms, non-branching, curved, folded in a loop or forming a tangle were discovered in a series of levels of the ocean mass. On glass slides submerged at depths 100 and 200 m were seen corkscrew-shaped twisted threads, on the rim of which were located a single series of fine granules.

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In the upper layer of water are met circular cells 1.5 μ in diameter, with flagella to 40 μ long or shorter (to 5 μ long); the latter generally formed colonies. Such flagellated microorganisms were found (Kriss & Rukina, 1952) in the upper level of the deepwater part of the Okhotsk Sea and adjoining regions of the Pacific Ocean.

From the odd, according to its morphology, microbial form it is necessary to note winding threads 1 μ across and from 30 to 40 μ in length, at one end of which are placed an agglomerate of oval bodies 0.5 to 1 μ in diameter. These forms, settling on glass slides which hung at depths 50 and 200 m, resemble Perseus marinus from the White Sea, described by Butkevich (1928) and also grape-like clusters of cells observed by Lebedeva (1953) in different levels of the Black Sea.

A unique kind possesses oval cells with very drawn out, gradually tapering end, sometimes with a round appearing bud. At depths down to 50 and 200 m these cells were located singly or in star-shaped figures. They suggest the fungus Mastigomyce philippovi (Imshenetski & Kriss, 1933).

The erythrosine dyed formations of oval, triangular, or irregular forms, settling on the glass slides from levels 0 and 200 m also attract the attention. Often are rounded bodies joined immediately with them like a bud, or with the latter seated on a long foot, going out from these formations.

In Table 1 is reduced data on the number of different morphological forms and general quantity of microorganisms on glass slides, remaining for a day at appropriate levels on the ocean in the region of the North Pole.

As seen in Table 1, in the main were encountered on the glass slides coarse spheres, oval and elongated cells. At the surface of the ocean they were counted in the thousands, and in similar quantity they were found on the glass slides located at depths 200 and 1000 m. At other depths they were found in hundreds and tens. A considerable number of ovals were seen in the form of colonies that attested to the propagation of these microbial forms on the glass slides.

Rod-shaped bacteria comprised the next most abundant group, but they were not found at all levels where oval cells are indicated. Evidently also, the latter were found in much greater quantity at depths 200 and 1000 m than were rod-shaped cells. As already indicated, micro-colonies of rod-shaped forms were generally observed side by side with singly lying rods. On the glass slides down to 150 and 200 m only singly lying bacteria were seen.

The smallest number found on glass slides are cocci-appearing microorganisms. They occurred in hundreds even at 0 and 1000 m, and in the remaining--tens and single. Comparatively the number in depths 25, 50, 75, 100, 250, and 400 m fell to merely single cocci. There were no microcolonies.

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The circumstance is very interesting that budding cells of yeast are found not only on the membrane ultrafilter, through which was filtered water from several depths of the ocean in the region of the North Pole (Kriss, Biruzova, Tikhonenko, Lambina, 1955) but also on glass overgrowing, upon which colony types are often concentrated. Apparently, some yeast are detected on glass slides from depths 0, 10, 25, 75, 150, 200, 1000, 1500, and 3000 m. Mostly they were counted in tens and at the surface in thousands.

Threadlike microorganisms are found in single number and even at depths 0, 1000, and 1500 m in tens. A unique twisting thread-like form with agglomerate of rounded bodies at one end are found in greatest number (326) on glass slides from depth 200 m.

In Table 1 also is shown the number of forms unusual according to their morphology. They appear in a series of depths and generally in tens.

The total quantity of microbial cells settling and propagating on glass slides is rather large at the surface of the ocean in the region of the North Pole, exceeding 10,000, but also on slides from depth 10 and 25 m the microbial census of overgrowing consisted of a thousand cells. Deeper the number of microorganisms decreased, in terms of hundreds, and later at depth 200 m an abrupt rise in the number was observed--to 3000. After this rise, new decrease to 100, 10, and a single, and at depth 1000 m a new increase in the number of microorganisms, equal almost to the surface layer. A comparatively high quantity of microorganisms are found on the slides at depth 1500 m. Still deeper almost "bare" glass from depth 2000 and 2500 m, in deeper layers microbial cells are counted in hundreds and tens.

The explanation of this, at first glance puzzling, increase of the number of microorganisms on slides at depths 200 and 1000 m lies in the hydrologic structure of the Arctic Ocean in high latitudes. These depths, for example, set the boundaries of the top and the bottom of the Atlantic current's penetration of the central districts of the polar basin. Also in experiments with glass slides, we encountered this phenomenon, that on the boundaries of contact of water masses conditions are created for greater development of bacterial life, apparently, owing to relative concentration of organic matter at the junction of water of different densities. Consequently, all the more fortified is the expressed (Kriss, 1955) confidence that microbiological research may help in characterizing the origin and dynamics of water masses, that is, to be used in the work of hydrology.

From data, shown in Table 2, it is easy to see that on slides from depth 200 and 1000 m, not only the quantity of microorganisms settling is accelerated, but also more interesting are the processes of propagation of the settled microorganisms. The number of colonies with 10 increased to 100 at the specified depth in comparison with higher and lower lying levels.

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Table 1

Number of different morphological forms of microorganisms settling and reproducing on glass slides submerged at different depths in the ocean in the North Pole region

Depth of water in meters	Cocci		Rods		Threads	Twisted thread clusters	Budding yeast		Coarse round & elongated oval cells		Unusual forms		Total No. of cells
	Single cells	No. in colony	Single cells	No. in colony	Single cells[2]	Single cells[2]	Single cells	No. in colony	Single cells	No. in colony	Single cells	No. in colony	
0	275	216	1862	3482	41	35	246	84	1372	2508	113	383	10617
10	42	4	236	275	4	0	29	13	135	174	15	79	1006
25	17	0	183	62	0	0	65	38	173	535	21	0	1104
50	4	0	54	106	0	*	0	0	160	132	0	24	480
75	11	0	93	192	3	0	40	0	23	86	0	0	448
100	32	81	56	181	0	0	0	0	53	30	12	0	445
150	20	0	116	0	0	0	11	80	73	182	9	37	528
200	21	91	100	69	2	326	28	0	1014	1269	49	22	2991
250	22	0	43	0	0	0	0	0	95	35	0	0	195
300	0	0	0	0	0	0	0	0	0	4	0	0	4
400	11	0	0	0	0	0	0	0	39	75	13	0	138
500	0	0	0	0	0	0	0	0	293	185	13	0	491
600	0	0	0	00	0	0	0	0	0	0	0	0	0
750	0	0	0	0	0	0	0	0	42	0	0	0	42
1000	0	124	327	355	11	0	50	0	4837	2528	59	0	8291
1500	13	42	214	44	34	0	52	39	179	191	25	0	833
2000	0	0	0	0	1	0	0	0	0	0	0	0	1
2500	0	0	0	0	0	0	0	0	0	0	0	0	0
3000	0	0	0	0	1	0	15	24	93	112	0	0	245
3300	0	0	0	0	0	0	0	0	0	48	0	0	48

Note: Zero expresses the number of microbial cells on slide in 8 cm^2 area

* Not computed, since occurred outside the 8 cm^2 rectangle sketched on slide

[2]Agglomerate of colony type not observed

Table 2

Daily production of microorganisms in different depths of the ocean in the North Pole region

Depth in meters	Micro-organisms in colony No.	Micro-organisms in colony %	Number of colonies	Number of microcolonies from 2 cells	3–5 cells	6–10 cells	11–25 cells	26–50 cells	51–75 cells	76–100 cells	>100 cells	Σ log m	N (sum colonies & single cells)	P/B
0	6673	62.8	1296	543	439	173	115	22	2	-	2	770.5	5240	0.576
10	545	54.2	104	49	28	12	9	1	1	2	2	64.8	565	0.456
25	635	57.5	153	55	64	33	-	-	-	-	1	86.8	622	0.552
50	262	54.5	39	22	4	12	1	-	-	-	-	21.1	257	0.312
75	278	62.1	97	76	10	11	-	-	-	-	-	38.8	267	0.576
100	292	65.7	67	13	35	19	-	-	-	-	-	42.0	220	0.720
150	299	56.6	51	-	31	20	-	-	-	-	-	36.7	280	0.504
200	1451	48.5	326	133	112	68	10	3	-	-	-	186.1	1866	0.384
250	35	17.9	10	-	10	-	-	-	-	-	-	6.0	170	0.144
300	4	100.0	1	-	1	-	-	-	-	-	-	0.6	5	0.480
400	75	54.3	43	32	11	-	-	-	-	-	-	16.2	106	0.600
500	185	37.6	54	31	11	12	-	-	-	-	-	26.7	360	0.288
600	-	-	-	-	-	-	-	-	-	-	-	-	-	-
750	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1000	3007	36.2	672	330	196	102	32	12	-	-	-	368.5	5956	0.240
1500	316	37.9	99	65	13	21	-	-	-	-	-	46.3	616	0.288
2000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2500	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3000	136	55.7	51	41	10	-	-	-	-	-	-	18.3	159	0.456
3300	48	100.0	24	24	-	-	-	-	-	-	-	7.2	24	0.120

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A significant number of microbial cells, disclosed on slides after submerging them 24 hours in different depths of the ocean in the region of the North Pole, developed in consequence of propagation of settled microorganisms; from 40 to 60% of all cells mostly occurred in microcolonies.

In the main, the mass of these microcolonies consisted of 2, 3-5, or 6-10 cells. Bigger microcolonies (from 11-15, 26-50 microbial cells) were discovered in the surface layer and at depths 200 and 1000 m. Several microcolonies on slides from depths 0, 10, and 25 m were made up of more than 50-100 cells.

The calculation of the number of colonies and the quantity of cells in each microcolony permitted the establishment of the rate of increase of microorganisms in different layers of the ocean in the region of the North Pole.

The increase of biomass of microorganisms after 24 hours, that is the daily coefficient P/B (Zenkevich, 1951) was computed from the formula of Ierusalimski (1954):

$$P/B = \frac{4\Sigma \lg m.n}{Nt} \times 24$$

where m = the average number of cells in each series of microcolonies; n = the number of microcolonies in each series; t = the time of stay of glass in the ocean; N = the amount of microcolonies and single cells.

From Table 2 is seen that the consequent mean daily coefficient P/B in the water mass of the Arctic Ocean varies in range from 0.12 to 0.72, that is, the daily gain in biomass of microorganisms results in increase of from 12 to 72%.

The amount of daily increase of microbial biomass in different levels of the ocean in the region of the North Pole is shown in Table 3; in the column "biomass of microorganisms" the figures for July station, obtained by the basic quantitative calculation of microorganisms on a membrane ultrafilter (Kriss, Biruzova, Tikhonenko, Lambina, 1955). As seen in Table 3, in the surface layer the microbial biomass in 8 mg/m^3 produces daily 4.5 mg/m^3. Deeper accordingly diminished microbial biomass production of microorganisms is expressed in tenths and hundredth mg in a cubic meter of water, and in deeper layers--in thousandths and 10 thousandths mg/m^3.

Owing to a determinable change in volume of microbial biomass per day, it is possible to judge accurately the activities of microorganisms on the mineralization of dead organic matter in the ocean in the region of the North Pole. For this computation we used the formula of N. D. Ierusalimski:

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$$P = A + B = amct + bmt$$

where P = total quantity of totally mineralized organic matter; A = quantity of organic matter, the energy of oxidation which is used in the increase of microorganisms; B = the quantity of organic material, the energy of oxidation which is expended in "basic exchange" of microorganisms (conservation of activity--without growth); a = coefficient, that is, the expenditure of energy material (in the form of organic matter) per unit increase of biomass of microorganisms; b = coefficient of basic exchange, that is, expenditure of energy material (in the form of organic matter) per needs "basic exchange" unit of biomass of bacteria per unit of time; m = biomass of microorganism (dry weight); c = coefficient of increase (unit increase of microbial biomass in the process of growth and propagation per unit of time); t = time.

By fundamental data of review of Vinberg (1946), Ierusalimski takes value (a) equal to 2 to 4, average 3; (b) as a day equals 0.3 to 0.8, average 0.5; dry weight is taken as 27% of wet weight.

Allowing that the average biomass of microorganisms in the photosynthetic layer (in ocean layer 0 to 50 m) at the North Pole in July amounted to 3.3 mg/m^3 or 0.66 mg/m^3 per dry weight, and the mean daily coefficient P/B, or as in this layer for example, equaled 0.5 of organic matter mineralized per day as a result of activity of microorganisms in the zone of Arctic photosynthesis:

$$3 \times 0.66 \times 0.5 \times 0.66 = 1.3 \ mg/m^3$$

For comparison one may note that the determination of the amount of mineralized organic matter per day in the zone of Arctic photosynthesis (0 to 50 m) in the Black Sea amounted to 6.5 mg/m^3 (Kriss, 1954) and in the Caspian Sea 11.2 mg/m^3 (Kriss, Biruzova, Rukina, 1954).

Our studies thus show that in every oceanic mass of water in the region of the North Pole microorganisms, with accompanying conditions necessary for their development, are found very important for cycling biogenous materials in the central region of the Arctic in the process of mineralization of organic matter. Together with this role in the biological productivity of water in the polar basin, all the more clearly emerges their potential value as hydrologic indicators for the characteristic origin and dynamics of water masses.

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Table 3

Quantity of daily increase of biomass of microorganisms in different depths of the ocean in the region of the North Pole

Depth of water	Biomass of micro-organisms	Daily coeffi-cient	Daily increase in microbial biomass	Ratio of daily production of microbes of biomass
m	mg/m^3	P/B	mg/m^3	B in %
0	7.8	0.576	4.5	58
10	1.5	0.456	0.69	46
25		0.552		55
50	0.5	0.312	0.15	31
75	0.5	0.576	0.29	58
100	1.2	0.720	0.86	72
150	0.8	0.504	0.40	50
200	0.3	0.384	0.11	38
250	0.3	0.144	0.04	14
300	0.1	0.480	0.04	48
400	0.11	0.600	0.06	60
500	0.15	0.288	0.04	29
600	0.02			
750	0.05			
1000	0.17	0.240	0.04	24
1500	0.05	0.288	0.014	29
2000	0.05			
2500	0.02			
3000	0.01	0.456	0.004	46
3400	0.007	0.120	0.0008	12

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